# THE METEOROLOGICAL MAGAZINE

HER MAJESTY'S STATIONERY OFFICE

September 1980

Met.O. 931 No. 1298 Vol. 109

METEOROLOGICAL OFFICE Met.O.931

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No. 1298, September 1980, Vol. 109

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551.506.3(424)

## A homogeneous rainfall record for the Cirencester area, 1844–1977

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**Summary**

Monthly rainfall records for the Cirencester area have been analysed for the years 1844–1977. A series of monthly totals comparable with those for the observing station at Baunton Waterworks has been produced. Comparisons with the rainfall record from Oxford are made to verify the homogenization.

### Introduction

Cirencester provides a wealth of material for the production of a composite rainfall record representing the town. All years since 1859, except 1884, have at least two sites operating within the town, and the neighbouring towns of Cheltenham and Oxford provide reliable values for comparison purposes. The town is situated in the extreme headwaters of the River Thames just to the south of the main Cotswold ridge, approximately midway between Swindon and Cheltenham.

### Availability of rain-gauge records

The map shown in Figure 1 marks the location of each rain-gauge referred to in Table I and the temporal extents of the various records are listed in this table. As can be seen from the map, most of the gauges are to the north and west of the town, particularly off the main road to Cheltenham which runs north-westwards from the town.

### Choice of key site and methods of comparison

The gauge at Baunton Waterworks is ideal for a key site as it is likely to be free of obstruction and is likely to remain in existence for some time to come. It is interesting to note that the earliest gauge in operation near Cirencester, Further Barton, was situated within a mile of the key site at Baunton.

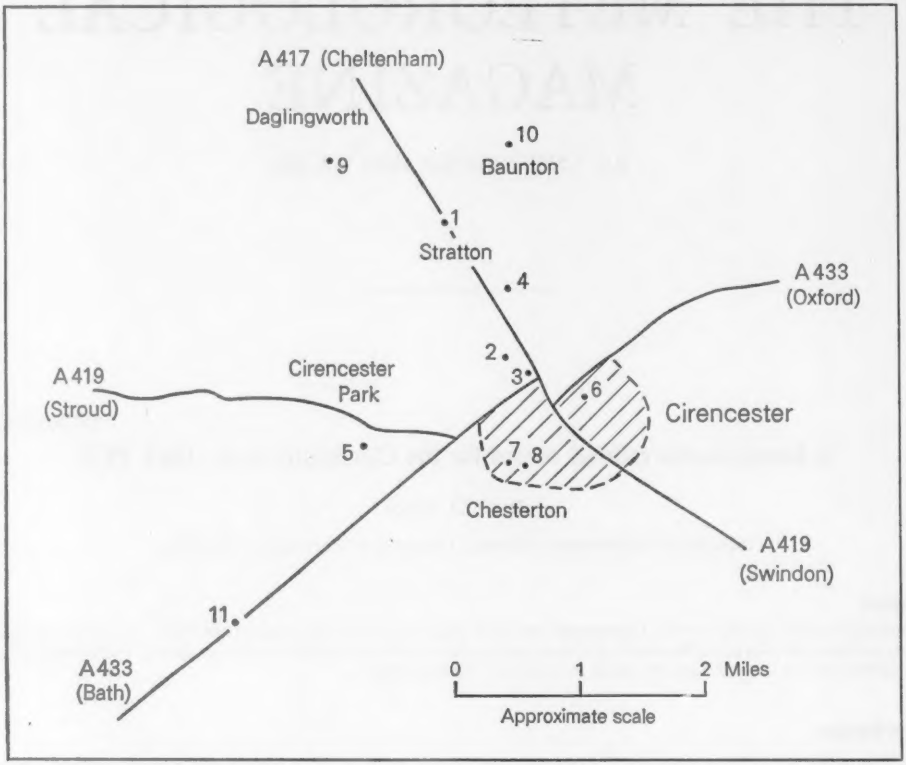


Figure 1. Rain-gauges in the Cirencester area (numbers refer to gauges in Table I).

**Table I.** *Gauges within the Cirencester area* (1844–1977)

| Gauge name | Location number (Figure 1) | First year | Last year | Missing years | Altitude (m) | Observer |
|---|---|---|---|---|---|---|
| Further Barton | 1 | 1844 | 1909 | 1884 | 129 | J. G. Brown 1844–83* |
| Cripps Mead | 2 | 1902 | 1929 | — | 111 | Wilfred Cripps |
| Dollarwood House | 3 | 1889 | 1924 | — | 111 | C. P. Hooker |
| 'The Firs' | 4 | 1869 | 1883 | — | 107 | J. Bravender |
| Royal Agricultural College | 5 | 1875 | 1914 | — | 135 | Principal |
| Gwynfa | 6 | 1923 | 1941 | — | 108 | N. Woods |
| Somerford Road | 7 | 1942 | 1956 | — | 115 | N. Woods |
| Chesterton Grove | 8 | 1957 | 1977 | — | 123 | N. Woods |
| Daglingworth Manor | 9 | 1924 | 1951 | — | 137 | J. Herbert Scrotton D. W. Harvey |
| Baunton Waterworks | 10 | 1948 | 1977 | — | 121 | Cirencester UDC |
| Thameshead | 11 | 1859 | 1869 | — | ? | J. H. Tannton |

* also Miss J. Brown (1885–1905) and C. P. Hooker (1906–09).

The method employed in this study is that of 'annual ratios' described by Craddock (1977).* The ratio of the year's catches at two rain-gauges is plotted against time and, in the ideal situation, the plotted points should vary about a straight line. The degree of variation and the level of the line relative to unity will naturally depend on the distance between the rain-gauge sites and the type of terrain within which the gauges are situated. Ratios between gauges within Cirencester should be near unity, whereas those between gauges some distance apart should vary about the ratio between the gauges' average annual catches.

Any climatic change affecting Cirencester town can be assumed to affect the region around. If, then, the ratios tend to deviate, the catch of either gauge, or the catches of both gauges, must have been affected by

(a) a change in site of either gauge, or

(b) a change in either gauge's local environment, generally a deterioration due possibly to vegetal growth, building construction, etc.

Changes due to (a) will generally be abrupt, while those due to (b) will be more gradual and take place over a length of time. With many gauges operating within Cirencester since the 1870s, it should be possible to discover which gauge is at fault, should any deviation from a straight line occur.

**Construction of a composite record**

Unlike many sites for which composite records have been produced (e.g. Norwich (Craddock, 1977)), no one site has a continuous record for more than about 30 years except Further Barton. However, many records exist and it is necessary to choose the best of those available. The major early gauge is at Further Barton. This was the only one in existence until 1859, and it is therefore the only one available for the first 15 years. Comparison of the Further Barton gauge with others in the town, at Oxford (Figure 2(a)) and at Cheltenham between 1844 and 1909, reveals three distinct periods: 1844–58, 1859–79 and 1880–1909. For the first and last periods the ratios remain steady, but at different reference levels, and are extremely consistent with other gauges, particularly those at Dollarwood House, Cripps Mead and the Royal Agricultural College (Figure 2(b)). However, the period between 1859 and 1879 is marked, firstly by an increase in rainfall caught, and then by a decline from 1870 to 1879. This latter decline is particularly evident when the Further Barton record is compared with that of 'The Firs' (Figure 2(c)), which is less than half a mile away, and with Oxford (Figure 2(a)). The decrease in catch at Further Barton from 1870 to 1879 can be explained by the infirmity of the observer. In the 10-year sheets stored at the Meteorological Office, the extreme age of the observer is commented upon on at least two occasions during the 1870s. He was possibly unable to cut down vegetation growth causing the gauge to be over-sheltered. It is therefore necessary to use 'The Firs' monthly totals for the period until 1882. For the period 1859–68 the Thameshead record is preferred to that at Further Barton. Comparison (Figure 3(a)) of the Thameshead gauge with that at Further Barton points to discrepancies in the latter gauge during this period as noted in comparisons with Oxford (Figure 2(a)).

After 1883, when the excellent record from the gauge at 'The Firs' ceases, 1884 has to be filled by the Royal Agricultural College, as it was the only gauge operating. From 1885 until the late 1920s there are generally three gauges in operation. The Royal Agricultural College gauge, when compared with Further Barton (Figure 2(b)), Cripps Mead (Figure 3(b)) and Dollarwood House, reveals very good internal consistency between 1883 and 1909. The gauge is also the only one that overlaps with 'The

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* Craddock, J. M. A homogeneous record of monthly rainfall totals for Norwich for the years 1836 to 1976. *Meteorol Mag*, 1977, **106**, 267–278.

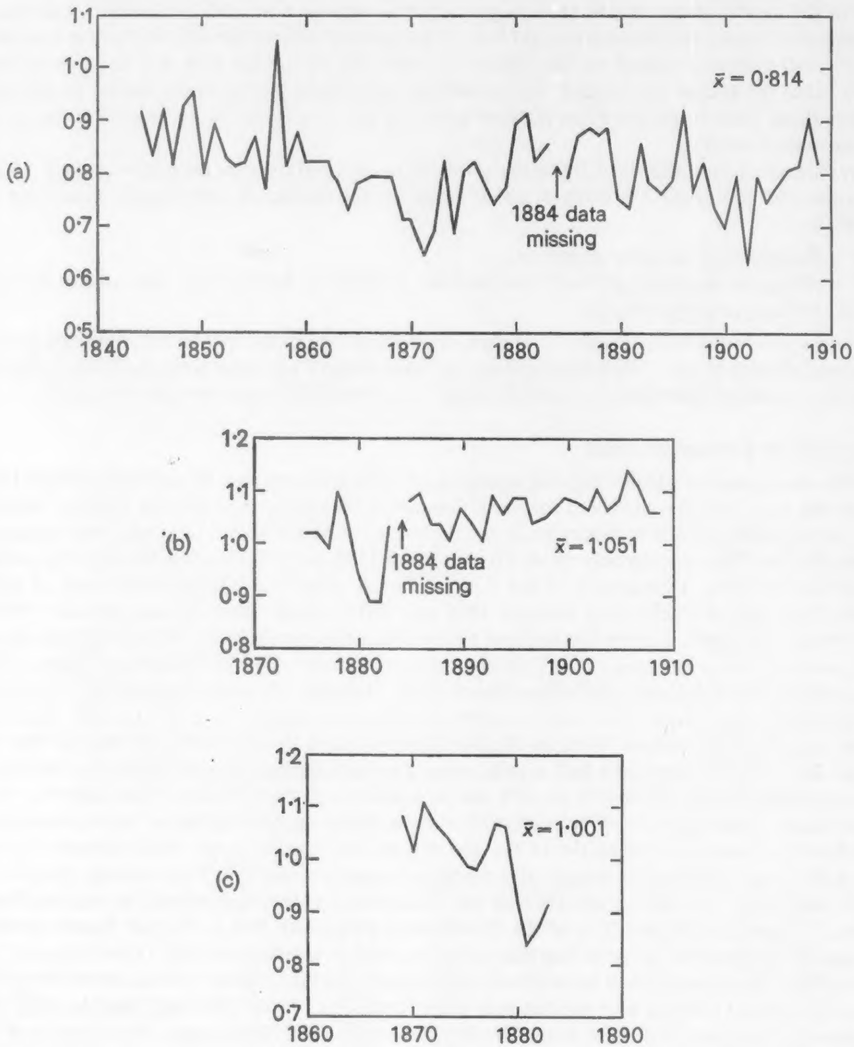


Figure 2. Ratios of annual catches: (a) Oxford/Further Barton, 1884–1909; (b) Further Barton/Royal Agricultural College, 1875–1909; (c) Further Barton/'The Firs', 1869–83.

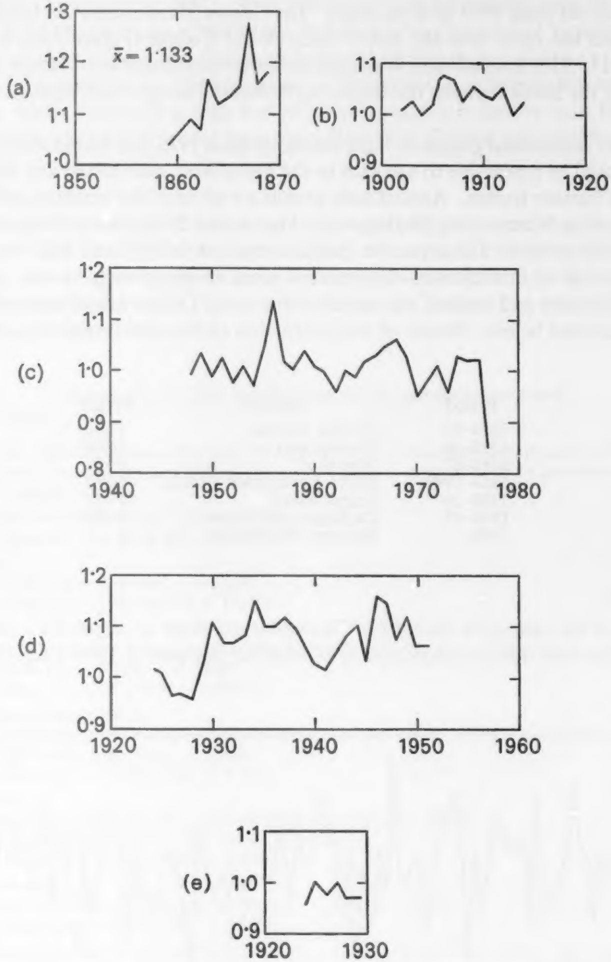


**Figure 3.** Ratios of annual catches: (a) Further Barton/Thameshead, 1859–69; (b) Cripps Mead/Royal Agricultural College, 1902–14 ($\bar{x} = 1·034$, $\sigma = 0·025$; $\bar{x} = 1·022$, $\sigma = 0·017$ (omitting 1906–09)); (c) Baunton/Cirencester (Woods), 1948–77 ($\bar{x} = 1·008$, $\sigma = 0·048$; $\bar{x} = 1·009$, $\sigma = 0·029$ (omitting 1956 and 1977)); (d) Daglingworth Manor/Cirencester (Woods), 1924–51 ($\bar{x} = 1·089$, $\sigma = 0·037$ (1930–51 omitting 1941)); (e) Cripps Mead/Cirencester (Woods), 1924–29 ($\bar{x} = 0·981$, $\sigma = 0·017$).

Firs' before 1882 and with Cripps Mead from 1902 to 1915 (since the Further Barton gauge records for the period 1870–80 have been shown to be in error). This record was, therefore, used until 1910, when the Cripps Mead record until 1929 took its place. The Cripps Mead record is excellent except for the years 1906–09, when the ratio with the Royal Agricultural College (Figure 3(b)) is 5 per cent above the value for 1910–14. This is also found in comparisons between Dollarwood House and Cripps Mead, which explains why the break between the Royal Agricultural College and Cripps Mead was chosen at 1909.

Mr N. Woods has maintained gauges at three locations since 1923, but all his sites are to the south of the town, and it would be preferable to use sites to the north-west, near to the key site of Baunton and the early records at Further Barton. Annual ratio graphs are given of the amalgamation of Mr Woods's three sites with Baunton Waterworks, Daglingworth Manor and Cripps Mead (Figures 3(c)–(e)) during the respective overlap periods. Discrepancies that are revealed in 1941 and 1956 can be explained by Mr Woods's relocation of instruments. The records from Daglingworth Manor up until 1929 also appear somewhat in error and explain the necessity for using Cripps Mead up until 1929. The final composite record is listed below. Details of the production of the appropriate factors can be found in Appendix 1.

| Period | Station | Factor |
|---|---|---|
| 1844–58 | Further Barton | 1·070 |
| 1859–68 | Thameshead | 1·108 |
| 1869–82 | 'The Firs' | 0·954 |
| 1883–1909 | Royal Agricultural College | 1·052 |
| 1910–29 | Cripps Mead | 1·029 |
| 1930–47 | Daglingworth Manor | 0·926 |
| 1948– | Baunton Waterworks | 1 |

**Concluding remarks**

Monthly values of the composite record for Cirencester are given in Appendix 2 and the ratio of the Oxford record to the new one at Cirencester is plotted for the period 1844–1975 (Figure 4). As the

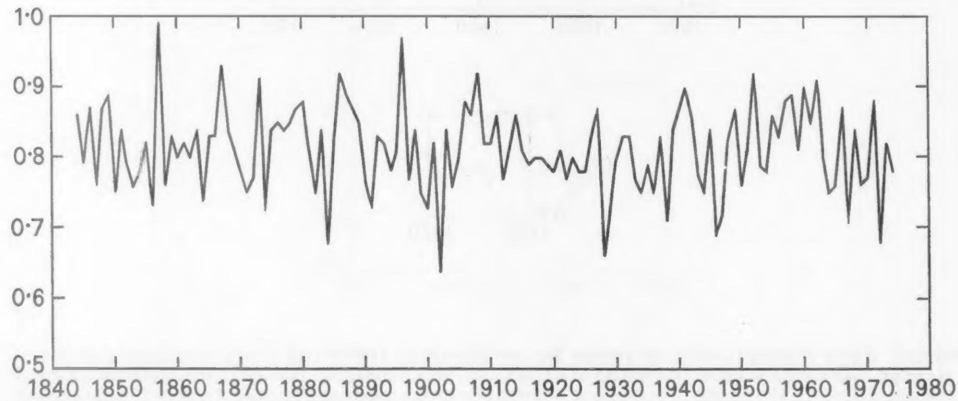


Figure 4. Ratios of annual catches Oxford/Cirencester.

Further Barton gauge is used for the first five years, the curve is the same as in Figure 2(a) albeit slightly shifted (owing to the multiplying factor of 1·070). For the period 1844–1975 the average annual ratio between Oxford and Cirencester is 0·811. This compares very favourably with the Oxford/Baunton ratio for 1948–74 of 0·818 and mean of the 1941–70 averages for Oxford and Baunton of 0·808.

It was not possible to incorporate earlier records extant for the region owing to the lack of overlap with gauges in the Cirencester area. The best record of this type is that kept at Stroud by Dr T. Hughes from 1771 to 1812. Short records (less than five years) are available in the towns of Bristol, Cheltenham and Gloucester but the gaps which would have to be filled from Oxford are considered to be too great.

**Acknowledgements**

The author wishes to thank the staff of the Agriculture and Hydrometeorology Branch (Met O 8) and the Archives (Met O 18e) of the Meteorological Office, Mr J. M. Craddock and Dr T. M. L. Wigley for useful discussions relating to the production of the composite record. The author also acknowledges the support of the Department of the Environment Research Contract No. 116/2/2.

## Appendix 1. The production of the composite record

1844–1958 *Further Barton*

The average ratio for Oxford/Baunton for 1948–74 is 0·818, with a standard deviation ($\sigma$) of 0·062. (The standard deviations between Cirencester gauges and Oxford are much higher than those within Cirencester owing to the greater distance between the gauges.)

Oxford/Further Barton (1844–58) = 0·875, $\sigma$ = 0·074.
Thus conversion to Baunton = 0·875/0·818 = 1·070.

1859–68 *Thameshead*
Oxford/Thameshead (1858–69) = 0·906, $\sigma$ = 0·054.
Thus conversion to Baunton = 0·906/0·818 = 1·108.

1869–82 '*The Firs*'
As the early years at the Royal Agricultural College (Figure 2(b)) are suspect, this ratio was produced from Oxford.
Oxford/'The Firs' (1869–83) = 0·780, $\sigma$ = 0·050.
Thus conversion to Baunton = 0·78/0·818 = 0·954.

1883–1909 *Royal Agricultural College*
Cripps Mead/Royal Agricultural College (1902–14 omitting 1906–09) = 1·022, $\sigma$ = 0·017.
Cripps Mead (1910–29) correction factor = 1·029.
Thus conversion to Baunton = 1·029/1·022 = 1·052.

1910–29 *Cripps Mead*
Baunton/Mr Woods's gauges (1948–74, omitting 1956) = 1·009, $\sigma$ = 0·029.
Cripps Mead/Mr Woods's gauge (1924–29) = 0·981, $\sigma$ = 0·017.
Thus conversion to Baunton — 1·009/0·981 = 1·029.

1930–47 *Daglingworth Manor*
Daglingworth Manor/Mr Woods's gauges (1930–51) = 1·089, $\sigma$ = 0·037.
Thus conversion to Baunton = 1·009/1·089 = 0·926.

It is worth mentioning the size of the standard errors of the estimates of these ratios. For a normal distribution the standard error is $\sigma/n^{\frac{1}{2}}$. Thus approximations for the standard errors of the conversion factors can be made. For those involving comparisons with Oxford, Further Barton, 'The Firs' and Thameshead they are in the range 0·03 to 0·04 and thus the third decimal place is not warranted. However, for those computed within Cirencester they are of the order of 0·01, thus justifying the third decimal place.

Appendix 2. A monthly rainfall record for the Cirencester region (units are tens of millimetres).

| | Jan | Feb | Mar | Apr | May | June | July | Aug | Sept | Oct | Nov | Dec | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1844 | 434 | 1033 | 462 | 55 | 27 | 190 | 544 | 462 | 489 | 884 | 1237 | 150 | 5967 |
| 1845 | 517 | 272 | 353 | 517 | 679 | 978 | 761 | 807 | 856 | 408 | 815 | 897 | 7860 |
| 1846 | 1264 | 381 | 508 | 992 | 600 | 299 | 584 | 1209 | 394 | 1699 | 462 | 272 | 8664 |
| 1847 | 753 | 653 | 489 | 429 | 625 | 789 | 388 | 250 | 706 | 1585 | 690 | 1046 | 8403 |
| 1848 | 332 | 1101 | 870 | 951 | 122 | 1332 | 837 | 789 | 1202 | 1373 | 446 | 987 | 10342 |
| 1849 | 522 | 476 | 245 | 842 | 911 | 468 | 326 | 253 | 1033 | 663 | 462 | 842 | 7043 |
| 1850 | 547 | 552 | 247 | 1177 | 951 | 296 | 1443 | 489 | 734 | 399 | 861 | 775 | 8471 |
| 1851 | 1101 | 231 | 1250 | 307 | 394 | 715 | 745 | 789 | 136 | 725 | 174 | 448 | 7015 |
| 1852 | 1549 | 462 | 136 | 190 | 544 | 1853 | 856 | 1541 | 1489 | 1055 | 2432 | 1168 | 13275 |
| 1853 | 1114 | 286 | 272 | 696 | 924 | 1033 | 1076 | 1011 | 508 | 1149 | 598 | 272 | 8939 |
| 1854 | 810 | 261 | 171 | 68 | 789 | 470 | 859 | 245 | 190 | 739 | 413 | 402 | 5417 |
| 1855 | 117 | 340 | 718 | 163 | 565 | 701 | 1318 | 557 | 617 | 1522 | 122 | 353 | 7093 |
| 1856 | 911 | 570 | 429 | 905 | 1073 | 346 | 353 | 1142 | 1073 | 911 | 299 | 794 | 8806 |
| 1857 | 824 | 422 | 530 | 706 | 478 | 794 | 671 | 353 | 489 | 1020 | 340 | 228 | 6855 |
| 1858 | 163 | 272 | 245 | 1427 | 720 | 865 | 544 | 535 | 799 | 478 | 226 | 696 | 6970 |
| 1859 | 422 | 433 | 724 | 735 | 397 | 948 | 394 | 720 | 859 | 766 | 673 | 771 | 7842 |
| 1860 | 735 | 568 | 692 | 428 | 1038 | 1725 | 453 | 1122 | 866 | 532 | 780 | 859 | 9798 |
| 1861 | 394 | 771 | 661 | 214 | 327 | 625 | 1061 | 146 | 768 | 413 | 1199 | 493 | 7072 |
| 1862 | 760 | 130 | 1351 | 695 | 1064 | 760 | 535 | 495 | 954 | 1115 | 194 | 464 | 8517 |
| 1863 | 828 | 155 | 304 | 318 | 298 | 996 | 124 | 830 | 833 | 1005 | 616 | 391 | 6698 |
| 1864 | 501 | 450 | 844 | 298 | 298 | 400 | 265 | 338 | 791 | 572 | 608 | 819 | 6184 |
| 1865 | 678 | 611 | 312 | 307 | 523 | 273 | 1379 | 1106 | 696 | 1475 | 886 | 439 | 8685 |
| 1866 | 1056 | 960 | 312 | 619 | 203 | 903 | 751 | 1013 | 1635 | 667 | 448 | 762 | 9329 |
| 1867 | 766 | 577 | 603 | 718 | 793 | 375 | 1044 | 658 | 402 | 560 | 276 | 594 | 7366 |
| 1868 | 968 | 391 | 676 | 543 | 391 | 113 | 121 | 1115 | 830 | 704 | 486 | 1568 | 7906 |
| 1869 | 1209 | 751 | 383 | 313 | 941 | 320 | 194 | 385 | 1405 | 477 | 603 | 1197 | 8178 |
| 1870 | 565 | 529 | 425 | 172 | 390 | 160 | 485 | 603 | 288 | 1027 | 458 | 552 | 5654 |
| 1871 | 439 | 368 | 354 | 812 | 378 | 719 | 1020 | 589 | 1357 | 371 | 165 | 530 | 7102 |
| 1872 | 1221 | 695 | 615 | 574 | 507 | 836 | 1127 | 793 | 390 | 884 | 1168 | 979 | 9789 |
| 1873 | 902 | 395 | 741 | 198 | 630 | 535 | 713 | 633 | 395 | 571 | 504 | 235 | 6452 |
| 1874 | 795 | 579 | 261 | 385 | 245 | 446 | 264 | 771 | 1320 | 923 | 681 | 674 | 7344 |
| 1875 | 1284 | 620 | 259 | 480 | 579 | 829 | 1347 | 293 | 678 | 1895 | 1221 | 398 | 9883 |
| 1876 | 596 | 1004 | 1064 | 899 | 157 | 354 | 238 | 727 | 1372 | 354 | 982 | 1827 | 9574 |
| 1877 | 1078 | 487 | 603 | 804 | 618 | 255 | 964 | 1529 | 508 | 565 | 1114 | 475 | 9000 |
| 1878 | 429 | 470 | 398 | 732 | 1125 | 730 | 223 | 1180 | 419 | 1042 | 826 | 429 | 8003 |
| 1879 | 884 | 1251 | 301 | 754 | 659 | 1180 | 914 | 1752 | 884 | 214 | 93 | 214 | 9100 |
| 1880 | 165 | 943 | 507 | 535 | 198 | 461 | 1773 | 387 | 1040 | 1399 | 739 | 903 | 9050 |
| 1881 | 363 | 1219 | 562 | 211 | 332 | 623 | 659 | 1301 | 543 | 494 | 1083 | 839 | 8229 |
| 1882 | 683 | 477 | 482 | 1056 | 507 | 921 | 1427 | 785 | 788 | 1524 | 1161 | 919 | 10730 |
| 1883 | 965 | 1013 | 291 | 168 | 385 | 1072 | 927 | 283 | 1104 | 716 | 1008 | 182 | 8114 |
| 1884 | 1010 | 406 | 612 | 380 | 264 | 793 | 970 | 569 | 387 | 278 | 497 | 986 | 7152 |
| 1885 | 711 | 930 | 307 | 564 | 620 | 451 | 142 | 572 | 1192 | 874 | 1473 | 264 | 8100 |
| 1886 | 1125 | 217 | 652 | 460 | 1199 | 248 | 863 | 462 | 700 | 1117 | 719 | 1128 | 8890 |
| 1887 | 644 | 165 | 401 | 340 | 432 | 369 | 254 | 427 | 719 | 665 | 679 | 441 | 5536 |
| 1888 | 241 | 500 | 956 | 358 | 588 | 708 | 1199 | 583 | 316 | 214 | 1510 | 866 | 8039 |
| 1889 | 214 | 420 | 821 | 732 | 986 | 270 | 751 | 949 | 460 | 602 | 422 | 457 | 7084 |

Appendix 2 *continued*

| | Jan | Feb | Mar | Apr | May | June | July | Aug | Sept | Oct | Nov | Dec | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1890 | 845 | 144 | 246 | 363 | 618 | 658 | 946 | 510 | 345 | 387 | 623 | 236 | 5921 |
| 1891 | 777 | 11 | 476 | 302 | 1037 | 380 | 1039 | 1577 | 420 | 2138 | 644 | 944 | 9745 |
| 1892 | 276 | 473 | 171 | 251 | 248 | 684 | 863 | 815 | 807 | 796 | 682 | 281 | 6347 |
| 1893 | 588 | 741 | 67 | 19 | 398 | 281 | 762 | 612 | 160 | 770 | 500 | 639 | 5537 |
| 1894 | 633 | 628 | 697 | 706 | 484 | 583 | 722 | 676 | 885 | 1355 | 1317 | 732 | 9418 |
| 1895 | 770 | 24 | 628 | 503 | 248 | 201 | 1088 | 713 | 217 | 741 | 1392 | 583 | 7108 |
| 1896 | 171 | 102 | 649 | 219 | 75 | 555 | 174 | 607 | 1692 | 970 | 201 | 850 | 6265 |
| 1897 | 602 | 962 | 890 | 593 | 305 | 802 | 446 | 1553 | 671 | 444 | 409 | 1088 | 8765 |
| 1898 | 125 | 328 | 125 | 470 | 817 | 299 | 201 | 777 | 241 | 973 | 716 | 831 | 5903 |
| 1899 | 1008 | 812 | 128 | 473 | 746 | 449 | 270 | 444 | 697 | 756 | 724 | 652 | 7159 |
| 1900 | 807 | 1553 | 254 | 217 | 481 | 636 | 331 | 1026 | 107 | 772 | 697 | 1411 | 8292 |
| 1901 | 272 | 291 | 618 | 833 | 331 | 593 | 758 | 639 | 724 | 396 | 243 | 1275 | 6973 |
| 1902 | 297 | 302 | 538 | 548 | 505 | 798 | 283 | 944 | 481 | 620 | 706 | 679 | 6701 |
| 1903 | 863 | 380 | 1008 | 673 | 1197 | 1263 | 885 | 959 | 781 | 1806 | 668 | 510 | 10993 |
| 1904 | 930 | 1256 | 358 | 352 | 764 | 321 | 984 | 692 | 802 | 182 | 473 | 569 | 7683 |
| 1905 | 224 | 187 | 1095 | 708 | 78 | 1144 | 165 | 1165 | 331 | 387 | 986 | 224 | 6694 |
| 1906 | 1085 | 430 | 449 | 195 | 515 | 855 | 350 | 288 | 174 | 1390 | 770 | 503 | 7004 |
| 1907 | 227 | 358 | 229 | 798 | 602 | 628 | 1066 | 462 | 163 | 1483 | 583 | 1395 | 7994 |
| 1908 | 689 | 236 | 735 | 676 | 513 | 168 | 521 | 1039 | 519 | 473 | 375 | 612 | 6556 |
| 1909 | 335 | 115 | 991 | 494 | 417 | 1144 | 599 | 932 | 802 | 1251 | 238 | 1275 | 8593 |
| 1910 | 645 | 1095 | 154 | 792 | 382 | 1022 | 599 | 1008 | 105 | 837 | 1059 | 1338 | 9036 |
| 1911 | 290 | 486 | 509 | 270 | 282 | 494 | 13 | 321 | 358 | 842 | 938 | 1461 | 6264 |
| 1912 | 1529 | 543 | 1320 | 42 | 696 | 1040 | 949 | 1730 | 222 | 988 | 463 | 1283 | 10805 |
| 1913 | 1273 | 411 | 972 | 1156 | 548 | 306 | 258 | 361 | 687 | 821 | 805 | 387 | 7985 |
| 1914 | 227 | 946 | 1008 | 358 | 407 | 677 | 967 | 395 | 458 | 562 | 1168 | 1584 | 8757 |
| 1915 | 1152 | 1205 | 334 | 316 | 918 | 458 | 1265 | 523 | 379 | 1116 | 554 | 1738 | 9958 |
| 1916 | 648 | 1338 | 1020 | 321 | 708 | 774 | 492 | 964 | 345 | 1785 | 677 | 1152 | 10224 |
| 1917 | 478 | 353 | 735 | 345 | 742 | 769 | 653 | 1702 | 643 | 1059 | 219 | 270 | 7968 |
| 1918 | 1008 | 484 | 377 | 679 | 481 | 304 | 941 | 623 | 1728 | 515 | 693 | 884 | 8717 |
| 1919 | 1226 | 821 | 1184 | 703 | 379 | 400 | 653 | 643 | 478 | 402 | 426 | 1242 | 8557 |
| 1920 | 998 | 248 | 735 | 1220 | 512 | 818 | 1234 | 300 | 450 | 630 | 324 | 860 | 8329 |
| 1921 | 753 | 94 | 484 | 261 | 465 | 73 | 120 | 515 | 478 | 413 | 659 | 407 | 4722 |
| 1922 | 815 | 1012 | 706 | 726 | 295 | 295 | 1310 | 1268 | 623 | 285 | 445 | 1025 | 8805 |
| 1923 | 643 | 1505 | 611 | 684 | 405 | 100 | 484 | 577 | 713 | 1291 | 538 | 901 | 8452 |
| 1924 | 1056 | 162 | 397 | 735 | 1775 | 726 | 1163 | 1030 | 1129 | 1158 | 567 | 1207 | 11105 |
| 1925 | 630 | 1054 | 107 | 460 | 1015 | 29 | 808 | 1108 | 1037 | 986 | 538 | 991 | 8763 |
| 1926 | 1315 | 565 | 173 | 878 | 967 | 489 | 548 | 536 | 295 | 724 | 1843 | 110 | 8443 |
| 1927 | 857 | 1020 | 862 | 416 | 298 | 969 | 944 | 1370 | 1422 | 538 | 653 | 915 | 10264 |
| 1928 | 1278 | 713 | 803 | 345 | 277 | 867 | 684 | 554 | 214 | 1312 | 981 | 839 | 8867 |
| 1929 | 300 | 193 | 58 | 270 | 747 | 353 | 463 | 531 | 71 | 1168 | 1937 | 1845 | 7936 |
| 1930 | 1096 | 145 | 524 | 762 | 287 | 588 | 1045 | 771 | 1011 | 555 | 962 | 901 | 8647 |
| 1931 | 532 | 585 | 47 | 672 | 938 | 950 | 962 | 1289 | 588 | 186 | 1188 | 435 | 8372 |
| 1932 | 889 | 33 | 501 | 765 | 1545 | 332 | 576 | 498 | 837 | 1321 | 623 | 270 | 8190 |
| 1933 | 631 | 941 | 933 | 301 | 478 | 367 | 508 | 219 | 729 | 884 | 266 | 156 | 6413 |
| 1934 | 748 | 82 | 623 | 534 | 261 | 480 | 767 | 527 | 759 | 544 | 412 | 1792 | 7529 |
| 1935 | 202 | 858 | 157 | 1341 | 318 | 927 | 249 | 417 | 1515 | 1320 | 1644 | 955 | 9903 |
| 1936 | 1063 | 593 | 536 | 562 | 330 | 530 | 1512 | 153 | 1077 | 386 | 868 | 1061 | 8671 |
| 1937 | 1181 | 1312 | 1086 | 811 | 597 | 270 | 703 | 171 | 449 | 837 | 468 | 585 | 8470 |
| 1938 | 997 | 254 | 66 | 26 | 644 | 498 | 640 | 1115 | 892 | 1037 | 944 | 953 | 8066 |
| 1939 | 1581 | 400 | 579 | 929 | 247 | 275 | 1446 | 534 | 287 | 894 | 1397 | 657 | 9226 |

Appendix 2 *continued*

| | Jan | Feb | Mar | Apr | May | June | July | Aug | Sept | Oct | Nov | Dec | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1940 | 663 | 748 | 670 | 569 | 510 | 188 | 826 | 44 | 179 | 974 | 1757 | 371 | 7499 |
| 1941 | 948 | 795 | 672 | 278 | 383 | 431 | 767 | 1037 | 193 | 588 | 595 | 487 | 7174 |
| 1942 | 880 | 282 | 579 | 348 | 1141 | 28 | 621 | 1058 | 496 | 870 | 440 | 1005 | 7748 |
| 1943 | 1445 | 296 | 258 | 179 | 820 | 548 | 334 | 670 | 498 | 654 | 496 | 395 | 6593 |
| 1944 | 536 | 223 | 78 | 440 | 223 | 781 | 644 | 936 | 748 | 985 | 1385 | 498 | 7477 |
| 1945 | 532 | 696 | 301 | 315 | 576 | 990 | 344 | 571 | 468 | 663 | 92 | 1195 | 6743 |
| 1946 | 793 | 642 | 296 | 524 | 849 | 877 | 518 | 2046 | 1077 | 134 | 1573 | 632 | 9961 |
| 1947 | 581 | 339 | 1996 | 698 | 362 | 494 | 765 | 122 | 444 | 99 | 513 | 597 | 7010 |
| 1948 | 1318 | 353 | 368 | 612 | 1107 | 696 | 241 | 846 | 638 | 1054 | 399 | 1102 | 8734 |
| 1949 | 345 | 396 | 450 | 437 | 686 | 218 | 541 | 376 | 353 | 1694 | 790 | 345 | 6631 |
| 1950 | 145 | 1740 | 404 | 655 | 632 | 541 | 1034 | 1034 | 1222 | 224 | 1509 | 498 | 9638 |
| 1951 | 1059 | 975 | 1001 | 833 | 711 | 358 | 544 | 1417 | 965 | 264 | 1750 | 691 | 10568 |
| 1952 | 544 | 201 | 732 | 610 | 678 | 447 | 61 | 937 | 284 | 1064 | 886 | 734 | 7178 |
| 1953 | 206 | 414 | 310 | 671 | 620 | 472 | 871 | 1217 | 734 | 599 | 409 | 229 | 6752 |
| 1954 | 419 | 866 | 864 | 97 | 432 | 1214 | 653 | 859 | 958 | 864 | 1565 | 638 | 9429 |
| 1955 | 671 | 424 | 427 | 257 | 1161 | 1008 | 97 | 152 | 185 | 455 | 864 | 1067 | 6768 |
| 1956 | 965 | 58 | 152 | 602 | 137 | 607 | 1077 | 1262 | 1019 | 417 | 251 | 1069 | 7616 |
| 1957 | 876 | 1008 | 775 | 81 | 399 | 386 | 838 | 907 | 1176 | 528 | 455 | 683 | 8112 |
| 1958 | 813 | 1059 | 399 | 221 | 655 | 859 | 780 | 605 | 1280 | 650 | 815 | 884 | 9020 |
| 1959 | 1138 | 33 | 706 | 815 | 376 | 437 | 612 | 592 | 43 | 538 | 747 | 1593 | 7630 |
| 1960 | 1247 | 747 | 396 | 277 | 455 | 869 | 1191 | 1166 | 1024 | 1250 | 1273 | 813 | 10708 |
| 1961 | 996 | 673 | 13 | 1303 | 333 | 356 | 681 | 572 | 615 | 739 | 318 | 1105 | 7704 |
| 1962 | 1085 | 147 | 310 | 665 | 488 | 69 | 480 | 1184 | 869 | 249 | 691 | 696 | 6933 |
| 1963 | 254 | 175 | 1097 | 655 | 399 | 1143 | 554 | 886 | 422 | 544 | 1570 | 318 | 8017 |
| 1964 | 163 | 340 | 884 | 584 | 625 | 602 | 251 | 163 | 208 | 361 | 439 | 932 | 5552 |
| 1965 | 859 | 56 | 663 | 541 | 460 | 836 | 950 | 389 | 1097 | 196 | 765 | 1875 | 8687 |
| 1966 | 551 | 1069 | 277 | 965 | 625 | 328 | 688 | 1105 | 348 | 1102 | 582 | 1006 | 8646 |
| 1967 | 594 | 1120 | 615 | 320 | 1702 | 292 | 470 | 447 | 1171 | 1725 | 574 | 749 | 9779 |
| 1968 | 909 | 470 | 302 | 838 | 714 | 1011 | 937 | 587 | 1455 | 798 | 734 | 963 | 9718 |
| 1969 | 777 | 551 | 625 | 381 | 1171 | 399 | 577 | 1313 | 224 | 76 | 965 | 927 | 7986 |
| 1970 | 947 | 627 | 490 | 668 | 305 | 658 | 691 | 617 | 818 | 348 | 1727 | 404 | 8300 |
| 1971 | 1392 | 366 | 620 | 546 | 627 | 1247 | 351 | 1039 | 203 | 917 | 688 | 409 | 8405 |
| 1972 | 940 | 970 | 635 | 551 | 808 | 521 | 297 | 384 | 396 | 348 | 737 | 1829 | 8416 |
| 1973 | 399 | 282 | 185 | 660 | 706 | 671 | 828 | 485 | 648 | 269 | 442 | 452 | 6027 |
| 1974 | 1355 | 1282 | 304 | 100 | 337 | 605 | 694 | 1106 | 1883 | 589 | 1087 | 647 | 9989 |
| 1975 | 1182 | 483 | 1108 | 454 | 214 | 88 | 589 | 464 | 920 | 188 | 581 | 458 | 6729 |
| 1976 | 294 | 363 | 334 | 131 | 390 | 245 | 162 | 366 | 1135 | 1197 | 607 | 1098 | 6322 |
| 1977 | 819 | 1591 | 836 | 456 | 478 | 1372 | 148 | 1679 | 261 | 596 | 868 | 839 | 9943 |

Mean values for period 1844–1977

| | Jan | Feb | Mar | Apr | May | June | July | Aug | Sept | Oct | Nov | Dec | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mean | 752 | 578 | 548 | 535 | 583 | 612 | 687 | 764 | 696 | 798 | 761 | 781 | 8095 |
| S.D. | 355 | 377 | 323 | 288 | 315 | 341 | 360 | 402 | 399 | 427 | 433 | 407 | 1421 |
| Skewness* | 0·10 | 0·78 | 0·98 | 0·54 | 1·12 | 0·76 | 0·35 | 0·67 | 0·63 | 0·68 | 1·09 | 0·68 | 0·33 |

* Skewness = (Mean − Mode)/Standard deviation.

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# Mesoscale surface humidity observations near the Home Counties tornado, 24 June 1979

By K. Grant

(Meteorological Office, Bracknell)

**Summary**

The mesoscale surface humidity field at the time of the Home Counties tornado of 24 June 1979 is depicted in different ways. Some tornado predictors are examined. Comments are made on the usefulness of the United Kingdom climatological station network for 09 GMT synoptic investigations.

## Introduction

At about 0830 GMT on Sunday 24 June 1979 a tornado caused damage to a housing estate in Dedworth, western Windsor, Berkshire (51°29′N 0°39′W), before moving north-north-eastwards on a heading of 029° across the racecourse, crossing the river Thames at Boveney Lock and causing further damage in the village of Eton Wick (Heighes 1979). Another report of wind damage came from King's Langley, Hertfordshire (51°41′N 0°27′W) (Buller 1979).

The time of the tornado almost coincided with the observing time, 09 GMT, of United Kingdom climatological stations, when dry- and wet-bulb temperatures, present weather, wind and total cloud amount for more stations than at other times are recorded as well as elements referring to the previous 24 hours, so it was decided to plot the observations in different ways to see if any consistent pattern emerged, particularly in the humidity field. Other sources of data were hourly synoptic observations, atmospherics (SFLOC) reports, Meteosat pictures and routine upper-air reports.

## Synoptic context

From the *Daily Weather Report* it was apparent that the tornado formed in association with a trough in the polar maritime air behind a cold front. There was a vigorous westerly flow over southern England with an area of slack low pressure to the north. It was seen from satellite pictures that the cloud corresponded to the model of a comma-shaped mass around a positive vorticity centre to the rear of a cold front.

## Description of the 09 GMT surface synpotic chart

At 09 GMT the cold front is over the North Sea, while a small low-pressure area, centre 1004 mb, is seen to be positioned near Reading with the trough extending southwards (Figure 1). The low had been moving north-eastwards on a heading of 060° at about 10 m s$^{-1}$ with little change of central pressure. Pressure tendencies are not large, the highest falling value being — 2·2 mb/3 h at Bracknell. An area of rain covers North Wales and the west and south-west Midlands; it is of moderate intensity over the Cotswolds to the north-west of the low. There is some light rain in Kent and Essex, corresponding to the 'tail of the comma' and showery precipitation in the south, both behind and ahead of the trough.

The tornado thus appeared about 40 km to the east of the low centre, in the forward right quadrant relative to the direction of motion. Thunderstorms were recorded at Bracknell (Beaufort Park), 15 km south-west of Windsor, between 0811 and 0835 GMT and at Hurley, 14 km west-north-west of Windsor, at 0815 and 0840 GMT. Surface winds were southerly ahead of the trough with a small area of south-east to easterly winds near the tornado. Dew-points were about 9 °C behind the trough and 11 °C ahead of it with the highest inland value 12 °C at Heathrow.

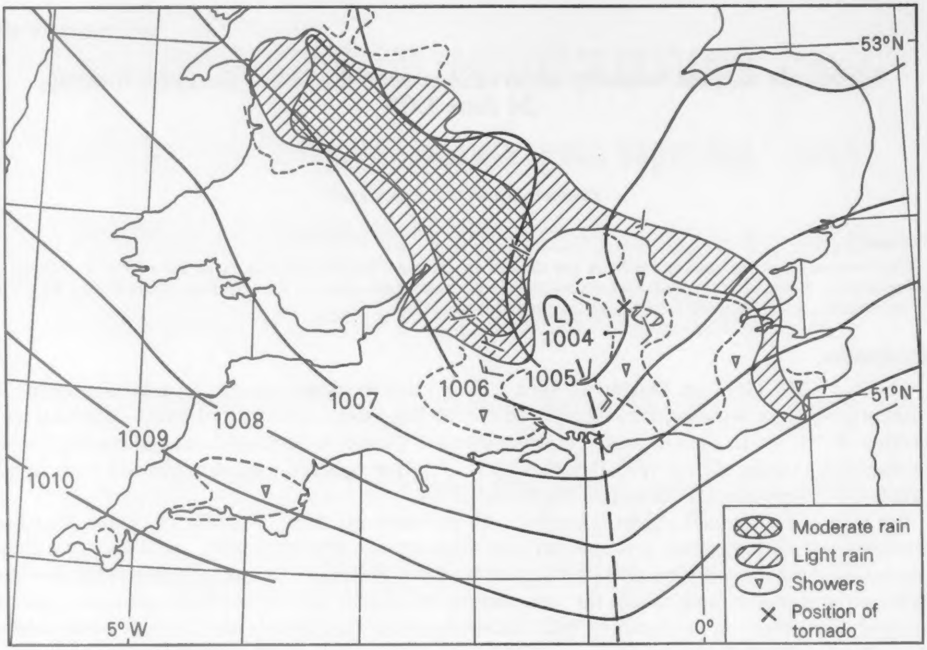


Figure 1. Mean-sea-level pressure and weather at 09 GMT on 24 June 1979.

**Humidity and cloud at 09 GMT**

Detailed mesoscale maps of the screen-level humidity field can be produced using observations stored on magnetic disc from the climatological station network, and plotted either by hand or by computer on to microfilm, from which paper enlargements can be made. Because of the dense network, single 'obviously' wrong values can be ignored when drawing up the charts if they are unsupported by neighbouring values. Wind arrows were also plotted on the original maps.

Three different representations were examined:

(1) *Dew-point* (not shown). This was calculated and plotted to a precision of 0·1 °C, though 0·2 °C or even 0·5 °C would suffice. Isopleths at 1 °C intervals were found to be appropriate. The chart is the simplest of the three to plot and the most familiar to forecasters.

(2) *Wet-bulb temperature reduced to sea level* (Figure 2). This parameter was preferred to wet-bulb potential temperature since an atmospheric pressure value is not needed for its calculation. Only a small proportion of co-operating climatological stations report pressure, and since July 1978 pressure has not been transferred to the archived data set for these stations. A saturated adiabatic lapse rate of wet-bulb temperature is assumed; this varies with temperature, but in the present case a constant rate of 5 °C/km has been used for simplicity. Isopleths are drawn at 0·5 °C intervals. This chart is perhaps

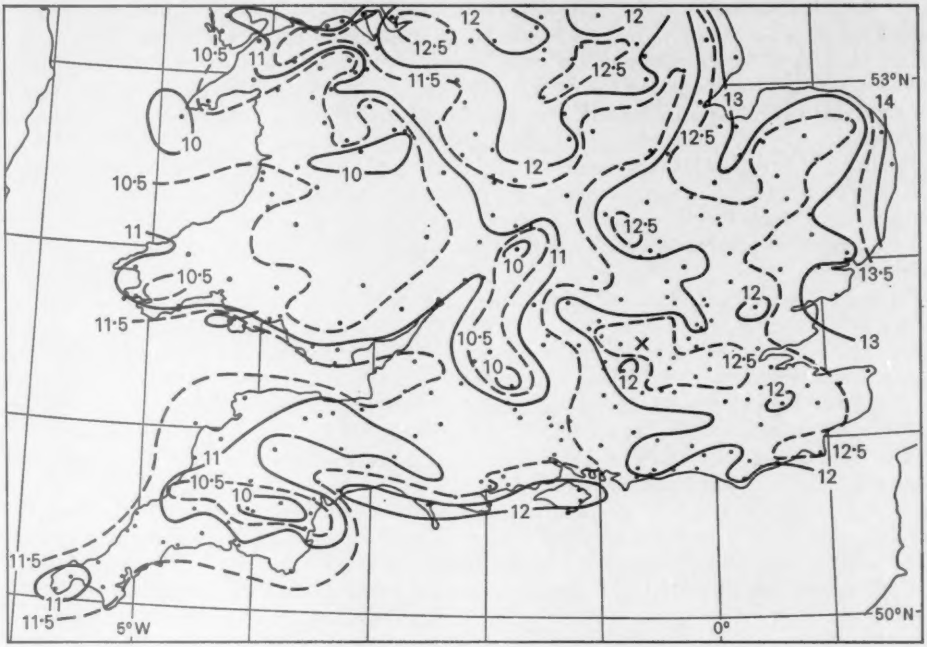


Figure 2. Wet-bulb temperature (°C) reduced to mean sea level at 09 GMT on 24 June 1979. The position of the tornado is marked by a cross. Dots indicate the stations used.

the best for representing variations of convective instability, assuming that upper-air temperatures change little in the mesoscale.

(3) *Wet-bulb temperature anomaly relative to June* 1979 *mean* (not shown). Here the mean 09 GMT wet-bulb temperature for 1–30 June 1979 at each station is subtracted from the value on the 24th. This is easily done by the computer, since all the values for a single month are stored together, and has the advantage that systematic thermometer and observer errors are mostly eliminated, though periodic or semi-random errors such as having different observers on different days of the week or occasional drying out of the muslin cannot be allowed for. A certain number of stations are lost here because of gaps in the record of more than a few days. The absolute values of the anomalies have little importance (on the 24th they were nearly all negative) but the pattern of wet-bulb temperature variation in the horizontal can be depicted with a large degree of confidence. Erroneous values are fewer and are easier to pick out. Anomalies at neighbouring stations often agree within 0·1 °C or 0·2 °C so that significant mesoscale differences of 1–2 °C can easily be distinguished by 0·5 °C isopleths.

The main features of the humidity field, as shown by all three maps, are (a) the moist air to the east and south-east of the low, (b) three tongues of less humid air to the west of the low, and (c) a rather irregular pattern to the north-east of the low, with higher humidity towards the cold front over the North Sea.

The tornado is situated near the centre of the most humid air, which stretches west-north-westwards from London as far as Oxford and appears to be associated with surface winds from the south-east quadrant. Highest dew-points are 12·2 °C at Hurley and 12·1 °C at Aldenham School (Hertfordshire), and Waddon and Bromley in south London. The highest wet-bulb temperature recorded in the area are 12·7 °C at Greenwich, 12·6 °C at Hurley and 12·5 °C at Heathrow, Wisley (Surrey), Waddon and Bromley.

The two centres of low humidity content to the north-west and south-west of the low are associated with the belt of continuous moderate rain. Further to the west, the cool polar maritime air is drier after passing over the Welsh mountains and Exmoor than after moving up the Bristol Channel.

To the north of London humidities are low where showers are breaking out ahead of the moist southerly winds.

Facsimile Meteosat pictures at half-hourly intervals were available for the period around 09 GMT, though resolution was poor. Dense white clouds were shown ahead of the low and behind it, but a dark patch was evident near or just to the east of its centre. This ties in with reports of 5 or 6 oktas of cloud from stations over the western Chiltern Hills, between Reading and Aylesbury. The rear edge of the cloud to both east and west was sharp, indicating cumulonimbus cloud.

The thunderstorm spawning the tornado did not give any SFLOC reports) these are coded hourly for the 10 minutes before the hour, so lightning activity may have either ceased by 0850, or been missed because of nearly simultaneous flashes from more active sources.

The highest dew-points ahead of the trough were at its northern end, to the east of the low. This moist air came from the south-west and may have had a longer sea track or a more southerly origin than the air to the south of it. The intrusion of the moist low-level air into a cold air mass would certainly cause potential instability, but the exact position of the tornado may depend on the detailed convergence and rotation of the low-level wind, which is not apparent from the surface winds at 09 GMT. The tornado occurred some 40 km ahead of the trough line, and winds away from the thunderstorm downdraught remained southerly for about an hour until the trough passed.

The topography may have had some influence on the tornado's formation. St Leonards Hill stands about 70 m above and to the south-south-west of the river with a fairly steep slope only 1 km upwind of the first grounding of the funnel cloud. The tendency for tornado formation in valleys or on the lee side of hills (Wright 1973) is therefore supported.

**Upper-air features and thunderstorms**

The intense upper trough over the British Isles was the most noticeable feature, with a strong jet bounding it. The tropopause within the trough was near 400 mb and the 1000–500 mb thickness about 541 decageopotential metres, very low for the time of year. At 300 mb the 100 kn isotach moved around the base of the trough at about the time of the tornado, an occurrence known to be favourable for cyclonic development. The most intense high-level horizontal wind shear was probably south of the area of interest, over the English Channel.

Thunderstorms broke out at first near the trough in the Thames Valley, then more widely in the afternoon in Kent, East Anglia and parts of northern England. There were only a few reports of hail at climatological stations, all of the hail being less than 10 mm in diameter except for some of 20 mm diameter at Manston. An interesting point is that the thunderstorms associated with this trough (and with the preceding cold front) were the only ones to affect climatological stations in England in the 38-day period 16 June–23 July 1979.

**Examination of tornado predictors**

The Americans have studied in detail the factors to be looked for in predicting tornadic activity. Alaka *et al.* (1973), studying surface predictors by regression methods, found that convergence of moisture at the surface was most relevant, though early in the day when surface winds were light or calm the best predictor was the horizontal gradient of moisture. The next most important parameters were convergence and vorticity (cyclonicity) of the surface wind, low pressure, and low stability of the atmosphere. Miller (1972), approaching the subject from a bench forecaster's viewpoint, emphasized moisture ridges, dry-air boundaries and low-level jets at 850 mb, dry tongues at 700 mb and various other parameters at 500 and 300 mb. (See also Crisp 1979.)

Examining these parameters qualitatively in the present case we see that:

(1) Moisture convergence is probably present just to the north of the main axis of moist air where winds are decreasing downstream. There is also convergence of moisture a little further west, near the centre of the low.

(2) The gradient of moisture at the surface is not particularly marked near the tornado, though it appears to be associated with a maximum absolute value. There is a drop of 2·5 °C in 60 km in reduced wet-bulb temperature near the low centre, but this is not unusually large.

(3) Surface wind confluence (and probably convergence) is marked on the trough-line, but not to the east of it, while cyclonic vorticity is present near the low.

(4) The pressure of 1005 mb is below average.

(5) The stability of the air is very low. Tropospheric wet-bulb potential temperatures are mainly in the range 8–10 °C compared with 12 °C at the surface ahead of the low (see Figure 3, Crawley 11 GMT ascent).

(6) A dry tongue of air at medium levels could have penetrated ahead of the trough, tying in with the cloudless slot shown by satellite. The Camborne radiosonde ascent at 02 GMT, just behind the trough, showed such air, with a dew-point depression of 17 °C at 787 mb (Figure 3).

(7) No low-level jet was found.

Figure 4 shows the 12 GMT 500 mb contours with 60 and 80 kn isotachs and plotted temperatures. The trough was moving east-north-east at 15 kn, so its position at 09 GMT would be about $\frac{3}{4}$ degree of latitude to the west-south-west of that shown. Also plotted are values of the Severe Weather Threat (SWEAT) Index (Miller 1972), which uses 850 and 500 mb parameters. The highest values behind the cold front are 195 at Crawley and Hemsby, well below the 400 required for tornadic outbreaks or 300 for severe storms in the United States. The largest contribution to the 195 was the stability term involving the 'total totals' (sum of 850 mb temperature and dew-point minus twice the 500 mb temperature) which reached 55·5 at Hemsby, quite a high value. The high SWEAT indices over central Europe were caused by strong upper winds or high 850 mb dew-points, or both.

Work is still proceeding in the United States on producing objective techniques for forecasting thunderstorms and tornadoes, mainly using regression methods on predictors derived from operational numerical model output and climatology (Reap and Foster 1979).

Tornadogenesis on the scale of an individual severe thunderstorm has been considered by Lemon and Doswell (1979). They state that when a supercell is collapsing and the updraught is decreasing, a rear-flank rotating downdraught starts to form at high levels and extends down to the surface, giving tornadoes. The horizontal velocity of the high-level wind compared with that of the updraught, and the dryness of the air, are relevant parameters. In the present case the maximum wind is only about 55 kn at around 300 mb, though the north-west to south-east gradient is large; any downdraught probably originated much lower down.

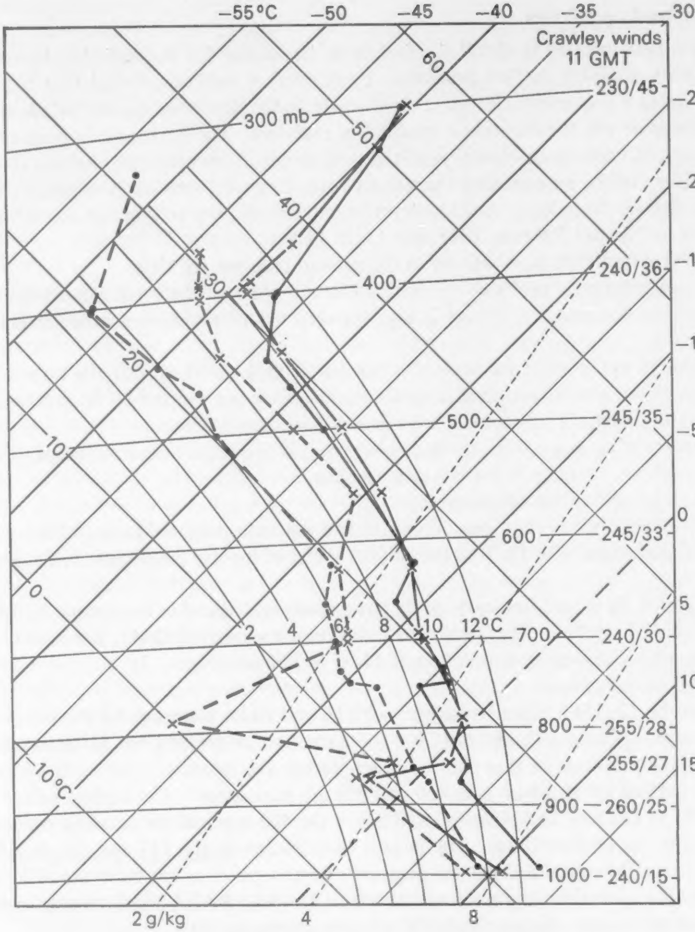


Figure 3. Tephigrams for 24 June 1979.
×——× (dry-bulb) and × - - - × (dew-point) Camborne 02 GMT
●——● (dry-bulb) and ● - - - ● (dew-point) Crawley 11 GMT

**Comments on the usefulness of the 09 GMT data set**

The humidity maps discussed above show that mesoscale maps of screen-level humidity over the United Kingdom can be drawn for 09 GMT from routine observations (available a month or two in arrears). Figure 5 shows the frequencies of distance from a station reporting a wet-bulb temperature on 24 June 1979 to the nearest similar station, for England, Wales and Scotland combined. A random distribution of the same number of stations over a square area of the same size would give distances

*Photograph by courtesy of J. W. F. Russell*

Plate I. Tornado at Windsor, Berkshire, 24 June 1979. (See page 259.)

*Photograph by courtesy of Evening Mail Ltd, Uxbridge*

Plate II. Tornado damage to cowshed at Little Common Farm, Windsor.

*Photograph by courtesy of Evening Mail Ltd, Uxbridge*

Plate III. Repairing a roof damaged by the tornado.

*To face page 263*

*Photograph by courtesy of Evening Mail Ltd, Uxbridge*

Plate IV. Tornado damage at Windsor.

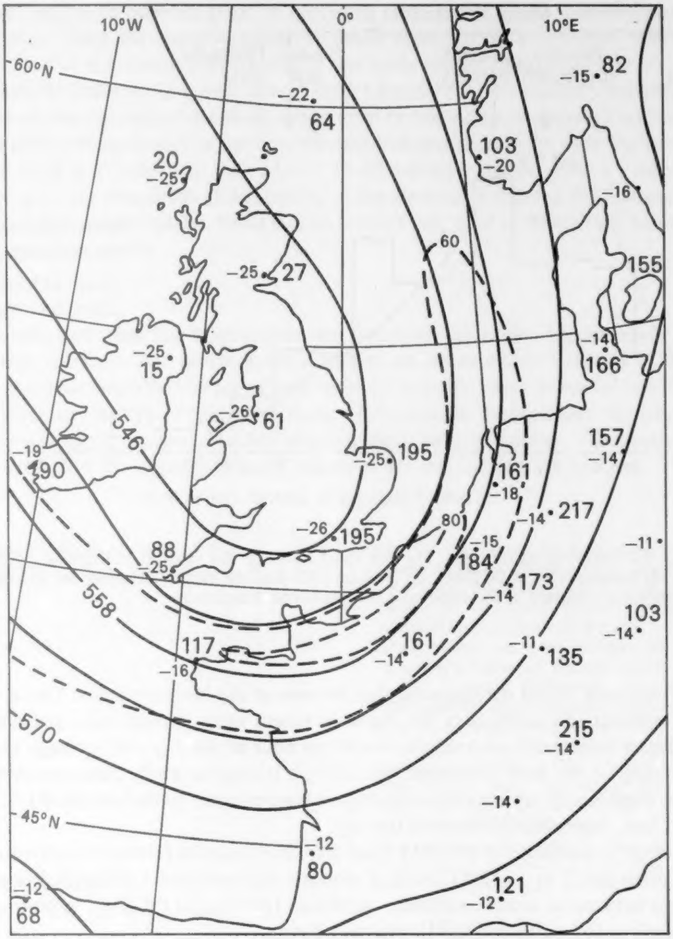


Figure 4. 500 mb chart for 12 GMT on 24 June 1979. Temperatures (°C) and SWEAT indices are also plotted. Continuous isopleths are labelled in decageopotential metres. Dashed isotachs indicate wind speed in knots.

shown by the dashed line, while equal spacing on a triangular grid would give a uniform distance apart of 23 km, neglecting edge effects, from the formula:

$$\text{distance} = (\sqrt{3}/2)^{-\frac{1}{2}}\ (\text{area/number of stations})^{\frac{1}{2}}.$$

The actual network is better (because of the reduced number of small spacings) than for random spacing, but has not nearly the desirable spacing given by a uniform grid of points.

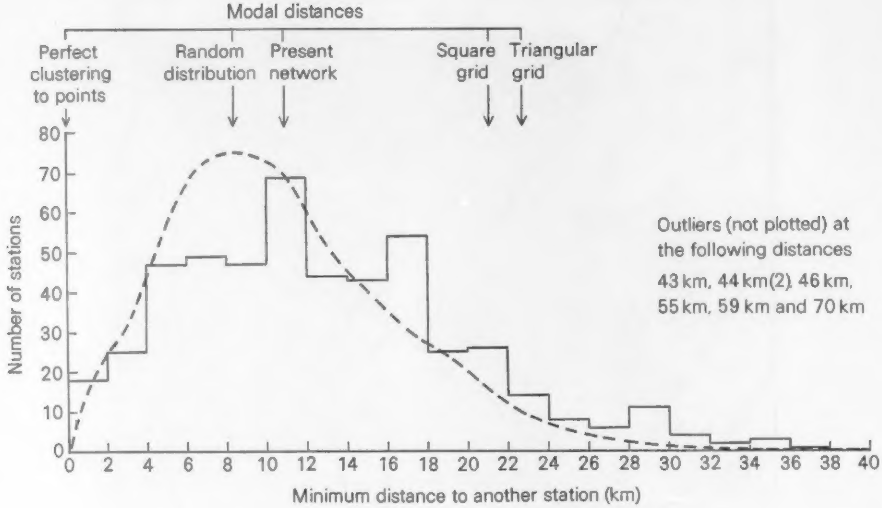


Figure 5. Spacing of climatological stations. The bar chart refers to 504 stations in England, Wales and Scotland reporting wet-bulb temperatures at 09 GMT on 24 June 1979 and the curve represents the spacing of 504 stations randomly distributed in a square of the same area (Monte Carlo simulation).

The 09 GMT data are stored on magnetic disc or tape at the Meteorological Office, Bracknell, for the years 1972 onwards. Synoptic data for the most recent years (temperature and dew-point to the nearest whole degree at present) are available for every hour of the day with average spacing of about 42–62 km, depending on the hour concerned (assuming a triangular grid). Also available are climatological hourly or fixed-hourly observations which give temperatures to the nearest 0·1 °C at an average spacing of 54–72 km, depending on hour of the day.

In quiet situations in summer the 09 GMT humidity chart may be relevant to afternoon or evening convection, but often the 12 or 15 GMT chart of synoptic stations (about 150 with dew-points, spacing about 43 km) will have to be used in addition. Atkinson (1977) used 09 GMT vapour pressures from climatological stations to investigate the Hampstead Storm.

For the whole of the United Kingdom on the particular Sunday in question the 09 GMT data set contained 495 reports of surface (10 m) wind, 476 of present-weather code figure, 527 of total cloud amount, 491 of visibility (coarse single-figure code at co-operating stations), 569 of dry-bulb temperature, 567 of wet-bulb temperature (from which dew-point, vapour pressure and relative humidity are derived) and 485 of state of ground. Similar 'daily' data sets record maximum, minimum and grass minimum temperature, rainfall, snow depth and days of snow, hail, thunder, gale, etc. Though the number of stations involved (Ogden 1978) is not as great as for rainfall, in case-study research the observations can delineate tongues of moist and dry air early in the day with an accuracy which synoptic observations cannot quite achieve. Inaccuracy and unrepresentativeness are more frequent than in synoptic data, but can be partially eliminated by the anomaly method or by more sophisticated quality control.

One important source of possible error in analysing case studies is the non-simultaneity of the 09 GMT observations. Once the observer agrees to make observations at 09 GMT there is no way of indicating to the user of the observation whether it was made late on a particular day, or whether indeed it is done regularly at times up to a half hour different from 0900. To position troughs etc. accurately on the mesoscale charts the time of the observation must be known to an accuracy corresponding to the time taken by a fast-moving feature in moving between one station and the next one downstream. For features moving at 10 m $s^{-1}$ this is of the order of 15–30 minutes, and for 30 m $s^{-1}$ only 5–10 minutes. Thus the resolving power due to the close spacing of the stations is negated for fast-moving situations if the timing is not known accurately. Most stations report very near to 0900 GMT but the investigator does not know which these are.

## Conclusions

The tornado occurred when the troposphere was extremely unstable. Upper winds overhead were not strong enough for American severe-weather indices to indicate severe storms or tornadoes. The factors which may have combined to set off this tornado were the extra potential instability above the most humid surface air, the dry air intrusion ahead of the trough, the increased vorticity caused by the approach of the small low-pressure area and possibly the local topography. Mesoscale climatological observations were useful in defining the exact extent of the moist air at the surface.

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# The use of analysis of variance in the assessment of rainfall variability

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**Summary**

Analysis of variance has been used by other workers to assess the significance of differences between the catch of two or more rain-gauges. It is suggested that analysis of variance may be an inappropriate technique for this purpose, in view of the very large 'within-cell' variations that can arise.

## Introduction

Analysis of variance is a statistical technique that may be used to test the significance of effects on a given phenomenon. In the context of rainfall studies it is possible to use the technique to test whether the rainfall at one gauge or more than one gauge is significantly different from that at other gauges. The gauges so selected can be placed in classificatory groups (for example altitude bands) so that it is the effect of the external factor (for example altitude) that is being assessed. Reported use of the technique is not common and it is the purpose of this paper to point out that there are serious problems in its application to rainfall data, which need to be more fully evaluated before application becomes more widespread.

The use of the technique raises two separate issues:

(a) whether the results using analysis of variance reflect the nature of reality with adequate sensitivity, and

(b) whether the technique of analysis of variance can, in principle, be applied to rainfall measurement, given the statistical requirements of the test.

The latter question is a technical one which it is relatively simple to assess. The former, however, raises problems which are more complex.

## Previous use of the technique

Two recent papers have been published which both refer to the analysis of rainfall data from the Plynlimon instrumented catchment of the Institute of Hydrology (Clarke, Leese and Newson (1975) and Newson and Clarke (1976)). It should be stressed at the outset that the points made in the present paper do not invalidate the findings of either of these studies but merely indicate that there may be further significant variations which may have been inadvertently ignored.

Both the papers referred to use rainfall data collected on a monthly basis. In the first, Clarke, Leese and Newson (1975) evaluated the relationship between rainfall totals and altitude bands, slope and aspects. They concluded, in general terms, that altitude had a significant effect on rainfall but that slope and aspect had no effect. The second paper (Newson and Clarke 1976) compares the catch of ground-level and tree-canopy-level gauges. In this, they conclude that there is no significant difference between the catches of the two groups of gauges.

It was this latter finding that initially raised doubts as to the appropriateness of the statistical technique employed. The finding, that the null hypothesis of no difference between ground-level and

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canopy-level gauges could not be disproved, seems to conflict to some degree with those of most other workers in the field.

Reynolds and Leyton (1963) for example reported an unpublished comment by Law to the effect that an unshielded canopy-level or mast-top gauge at Stocks Reservoir, Yorkshire, recorded about 15 per cent less than a standard ground-level gauge at an equivalent site. In their own work Reynolds and Leyton reported that canopy-level gauges which were carefully 'nested' in the canopy (that is to say placed as low as possible in the canopy to obtain shelter from the wind, yet not so low as to be affected by interception or splash) recorded an average 2 per cent lower than standard ground-level gauges. Canopy-level gauges equipped with shields of various types recorded about 1 per cent less than their ground-level equivalent. In the work by Clarkson (1973) it was reported that a mast-top gauge under-recorded by 'less than 2 per cent' over a two-year trial period. All the canopy-level gauges used in the analysis by Newson and Clarke (1976) were 'nested' in a similar way to those of Reynolds and Leyton (Newson, personal communication).

**An example of the application of analysis of variance**

In connection with a study of rainfall interception by coniferous forest, rainfall was measured in four rain-gauges at sites at Macclesfield Forest, Cheshire. Measurements were taken on a weekly basis and periods which included snowfall were excluded from the analysis. The field area of the study covered part of the western flanks of the Pennines, ranging in altitude from 260 m to 365 m. Three of the gauges were installed with their apertures at ground level and were surrounded by baffle-plates, while the fourth was installed at canopy level and 'nested' as described in the previous paragraph. Over a 78-week period the total rainfall measured was as shown in Table I.

**Table I.** *Rainfall totals for the four rain-gauges analysed at Macclesfield Forest.*

| Rain-gauge | Type | Altitude (m) | Rainfall over 78-week period (mm) |
|---|---|---|---|
| A | Ground-level | 260 | 1338·5 |
| B | Canopy-level | 345 | 1357·3 |
| C | Ground-level | 335 | 1462·1 |
| D | Ground-level | 365 | 1383·8 |

One-way analysis of variance was used to assess the variance between pairs of gauges in turn:
(a) A and D (i.e. 'low-altitude' and 'high-altitude'), and
(b) B and C (i.e. canopy-level and ground-level).

The one-way analysis of variance procedure follows that described by Snedecor and Cochran (1967). Briefly, it involves the calculation of the $F$-ratio from:

$$F = \frac{SS_A/(k-1)}{SS_{\text{error}}/(N-k)},$$

where

$$SS_A = \sum_j N_j(\bar{Y}_j - \bar{Y})^2 \text{ (the sum of the squares 'between sites')}$$

in which $\bar{Y}_j$ is the mean of the variable $Y$ in the category $j$ and $N_j$ is the number of cases in the category $j$, and

$$SS_{\text{error}} = \sum_j \sum_i (Y_{ji} - \bar{Y})^2 \text{ (the sum of squares 'within sites')},$$

and

$$k = \text{number of sites.}$$

Analysis of variance is a parametric technique in which it is required that the data should be normally distributed, although this requirement is not absolute and can be relaxed to a certain degree. Nevertheless, since the weekly data were negatively skewed, they were first subjected to a logarithmic transformation. (Clarke *et al.* did not employ any transformation on their raw data (Clarke, personal communication), although it is important to note that they used monthly data in their study and the distribution of these data would tend to approach the normal more closely than weekly data.)

A further requirement for analysis of variance is that the variables are statistically independent. This requirement is not, however, absolute and it is clear that the longer each rainfall total period is, the greater likelihood there is that this requirement is satisfied. Hence, for example, daily rainfall totals would grossly violate both this requirement and that for normality. On the other hand, monthly totals would be unlikely to violate either. The weekly data given in this example having been subjected to a logarithmic transformation, it is most unlikely that either of these requirements is violated to a significant extent.

The results from the analysis of variance in the present study are given in Table II. Comparisons of the calculated $F$-ratio with the $F$-distribution show that there was no significant difference in the case of either of the the tested pairs of data sets (a) and (b) in the Table.

**Table II.** *Results of the analysis of variance of Macclesfield Forest rainfall data*

Data set (a): Rainfall at A v. rainfall at D

74 weekly records

| Source | Degrees of freedom | Sum of squares | Mean sum of squares |
|---|---|---|---|
| Between sites | 1 | 0·8936 | 0·8936 |
| Within sites | 146 | 479900·3996 | 328·0849 |
| Total | 147 | 479901·2932 | |

$F$-ratio = 0·0027 (not significant at $p = 0{\cdot}05$)

Data set (b): Rainfall at B v. rainfall at C

75 weekly records

| Source | Degrees of freedom | Sum of squares | Mean sum of squares |
|---|---|---|---|
| Between sites | 1 | 90·6371 | 90·6371 |
| Within sites | 148 | 48428·8299 | 327·2218 |
| Total | 149 | 48519·4669 | |

$F$-ratio = 0·2750 (not significant at $p = 0{\cdot}05$)

(It should be noted that in simple two-variable cases, such as those presented here, it is possible to use a $t$-test to establish whether the means of the records from the two rain-gauges are significantly different: in both cases (a) and (b) the $t$-test also demonstrated that there was no significant difference at the $p = 0{\cdot}05$ level.)

## Discussion and conclusions

The conclusion that analysis of variance showed no difference between the sites was initially surprising, particularly in view of the comparison of rainfall totals (Table I). However, examination of the data suggests that the inherent variability of the rainfall data acts as a major source of variation in the analysis. This variation is picked up in the within-cell variability and will therefore tend to reduce the significance of the between-cell variability. In Clarke's cases the (within-cell) rainfall variability will tend to be less than in the Macclesfield Forest example because data for his work were analysed on a monthly basis. (As already noted, this will also have the effect of reducing the skewness of the data.)

Any assessment of the efficiency of analysis of variance partly hinges on the definition of 'significant', not only in a statistical sense but in its wider use. Hence, for example, Reynolds and Leyton (1963) seemed to indicate that a 2 per cent deficiency in catch should be regarded as significant, whilst Clarkson (1973) implied that the 'less than 2 per cent' deficiency he noted was insignificant. The decision as to what is significant obviously depends partly on the error levels elsewhere in the study, and, in the context of the Macclesfield Forest study quoted, a 2 per cent error would be considered insignificant.

A further argument against the use of analysis of variance (and indeed of most relatively sophisticated statistical techniques) with rainfall data is that it involves the artificial delineation of units which are analysed as if they were naturally discrete in time. In reality, rainfall is more akin to a continuously changing variable over time.

To return to the two aspects of the problem raised in the introduction to this paper it is clear that, firstly, the use of analysis of variance imposes an implied structure on the reality of rainfall data which may not reflect reality with sufficient sensitivity. Secondly, although the technique can validly be applied with care to rainfall data there are pitfalls which must be avoided if the results are not to be ambiguous. In particular its use with short-period data (less than month-long) raises special difficulties.

**Acknowledgements**

Although the opinions in this paper are entirely those of the author he would like to thank Mr R. T. Clarke and Anna Newson (Institute of Hydrology) for providing helpful additional information. Thanks are also due to Dr S. Nortcliff (University of Reading) for helpful discussion and to the North West Water Authority for co-operation in the collection of field data.

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# An invitation to form a meteorological system of observations by world-wide agreement

By James Jurin, M.D.

Secretary of the Royal Society, Fellow of the College of Medicine, London
(London, Royal Society, *Philosophical Transactions*, **32**, 1722, 422–427)
*Translated from the Latin by Dr J. G. Landels, University of Reading*

The various conditions of the sky, and of the air which we breathe, that is to say the changes and alterations of cold and heat, of dryness and humidity, particularly those which are great and sudden, are rightly considered to be factors in the health of the human race. Not only Doctors, but also men of all ages (past and present) who have been keenly interested in Natural Philosophy have asserted that effort and work spent in observing these phenomena is not to be despised. In the last century, instruments and mechanisms have been devised by the ingenuity and effort of Philosophers, by means of which movements and changes in the weight, heat, humidity and (*elateris*)* of the air can be instantly presented to view, and at the same time submitted to weighing and measurement of a very delicate and accurate kind.

And these distinguished men did not see fit to stop there, but, driven by zest for study and desire for knowledge, strove to investigate the causes of these changes, where it was possible. To this end they made careful notes in their diaries of the readings taken from the recently invented instruments of the weight, humidity and temperatures of the ambient (air), and added observations on the appearance of the sky and the weather, the winds and the amount of rain; these notes can be found scattered about in the *Acta Philosophica* and elsewhere.

It would be difficult to find a better method or system of observation than that. But just suppose there were observers in suitable numbers, appropriately distributed over a large area of the earth's surface; and, ultimately, someone to collate their various diaries, and make notes of the agreements and discrepancies; we should then before long have a Meteorological History covering a number of years, of a kind that could hardly be imagined or even dreamed about today.

We find that there is general acceptance of the view that sudden changes in the weather are to be attributed to the wind; and when it became possible, by the system of observations described above, to discover in what regions they originate, what course they follow, at what times (or for how long) and over how great an area of the world's surface, with this knowledge the way might be opened to an understanding of the causes and origin of winds. At any rate this theory (i.e. that winds cause changes in the weather) which has a very important bearing on our present subject, and which is generally regarded as a reasonable hypothesis, we would be able to prove either true or false by reliable observations. I quote the opinion of that most learned of men, Edmund Halley (*Philos Trans R Soc* No. 181) that the mercury rises in the barometer because the winds, blowing on either side from opposite points thicken the air and, as it were, pile it into a heap; and on the contrary the mercury falls because the air is carried away from that place by winds blowing in diverse directions, and, as it were, is drained away.

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* *elateris* in the original is a misprint; the context suggests 'wind force or direction' (perhaps *flationis* or *flatilis*? or *lateris*, of the quarter).

Educated people, therefore, who are willing to contribute some effort towards the perfection of this branch of Natural History are asked to note in a diary, at least once every day, or oftener whenever possible, the height of the barometer and thermometer, the wind direction, with an estimation of its force, the state of the sky and the amounts of rain and snow which have fallen since the previous observation; and should anyone wish to add observations of the hygroscope, or observations made with the aid of the magnetic needle, these would not be unwelcome.

Should a violent storm befall it would be profitable to have an accurate plotting of its beginning, growth, peak of violence, decay and ending, accurately recorded together with notes of the times and heights of the barometer corresponding to these times.

We advise those who are skilled enough to make and fill a barometer themselves to use the common or so-called open barometer. The tube should be at least one-quarter or even as much as one-third of an inch wide, because in a narrower tube the mercury has been found to subside below the true height (*Philos Trans* No. 363). The diameter of the cistern, or mercury reservoir, should be at least eight or ten times that of the tube, in order that whether the mercury ascends or descends in the tube its level in the cistern will remain constant, or at least change very little.

Those, indeed, who prefer to use the closed, or portable barometer may obtain such a one, made with the greatest diligence, from that notable instrument maker Francis Hawksbee, in the area commonly known as Crane Court, London, who also will provide thermometers marked with that scale, or graduation marks, engraved with particular care,* which he has already made familiar to men of science for many years.

Those, however, who use a differently constructed thermometer are asked to be so kind as to note in the diary the site of the thermometer, its construction, arrangement of degrees on the scale, and the maker's name from whose workshop it came. We judge the most suitable site for a thermometer to be in a room facing north, where a fire is never, or at least very rarely, lit.

So that the diaries may the more easily be compared it is desirable for them all to be in the following form:

The first column should show the day and hour of the observation; we particularly ask that observers use the old, or Julian, style; the second should show the height reached by the mercury in the barometer above the level of the mercury in the reservoir in inches or twelfth† parts of the London foot, and tenths parts thereof. The London foot is to the Paris foot as 15 is to 16 approximately; the third column should show the degrees and tenth parts which the spirit reaches in the thermometer, the fourth should represent the direction and force of the wind, the force always being represented by one of the sequence of numbers 1, 2, 3, 4 of which 1 signifies the most gentle motion of the air, scarcely stirring the leaves of trees, 4 the very peak of a violent wind, 2 and 3 intermediate between these limits and zero or 0 denoting a flat calm, the fifth should be occupied by the state of the sky and a brief description of the weather, and the sixth and last should show the amount of rain and melted snow which has fallen since the previous observation measured in London inches and tenths. This may easily be estimated by means of a funnel about two or three feet in diameter, a container for receiving the water which flows down the funnel, and a measuring cylinder with a scale divided into inches and tenths.

The funnel should be sited so that whichever way the wind blows no part of the rain shall be intercepted by any building or any other obstruction. The container for holding the rainwater should be everywhere well closed to prevent evaporation, save for one narrow hole to receive the rainwater from

* This could mean that the scale is well engraved, or that it is a particular scale.

† The author here uses *digitus* which is normally understood to mean $\frac{3}{4}$ inch, i.e. one-sixteenth part of a foot.

the funnel above. The diameter of the measuring cylinder should be a tenth part of the diameter of the funnel so that one inch of water in the measure represents a hundredth part of one inch falling into the funnel and therefore on the surrounding area, and similarly for each decimal part of an inch.

At the end of each month and each year the monthly and annual mean heights should be reckoned, of the barometer and the thermometer, and also the total amounts of rain for each month and each complete year. The mean heights can be calculated by adding together all the barometer heights, also the thermometer readings, either the morning readings or the daily maxima (which of course occur about the third or fourth hour of the afternoon), and dividing that sum by the number of days.

We ask all who are willing to undertake all, or any, of the above observations to send copies of their diaries covering each year to the Secretaries of the Royal Society so that they may be gathered together in one diary which will be prepared in London by the order of the Royal Society. It is planned that whatever can be deduced from the collation of these diaries will be communicated to the public each year in *Acta Philosophica*.

Form of Diary

| Day & Hour 1723 | Barom. height inch tenth | Therm. height deg tenth | Wind | Weather | Rain inch tenth |
|---|---|---|---|---|---|
| November | | | | | |
| 1. 8 a.m. | 29·75 | 49·6 | S.W. 1 | sky covered by clouds | 0·035 |
| 4 p.m. | 29·56 | 47·3 | S.W. 2 | intermittent rain with sun in between | 0·043 |
| 2. 7 a.m. | 29·24 | 48·5 | S. 1 | almost continuous rain | 0·725 |
| 3. 9 a.m. | 29·95 | 49·7 | N. 1 | clear sky | 0·032 |
| 5 p.m. | 30·4 | 49·2 | N. 1 | clear sky | 0·000 |
| 4. 7 a.m. | 29·9 | 47·0 | S.W. 1 | scattered clouds | 0·000 |
| 10 | 29·7 | 46·2 | S.W. 2 | intermittent rain | 0·103 |
| 12 | 29·4 | 45·0 | S. 3 | sky almost everywhere covered with clouds | 0·050 |
| 3 p.m. | 28·8 | 46·0 | S. 4 | scattered clouds | 0·000 |
| 5 | 28·6 | 47·2 | S.W. 4 | sky unchanged | 0·000 |
| 7 | 28·9 | 48·0 | S.W. 2 | it rained | 0·000 |
| 9 | 28·9 | 48·2 | 0 | almost continuous rain | 0·305 |
| 5. 7 a.m. | 29·7 | 53·4 | N.E. 1 | clear sky, frost | 0·250 |

# Reviews

*The atmosphere: endangered and endangering,* W. W. Kellogg and Margaret Mead (Scientific Editors). 230 mm × 155 mm, pp. xii + 154, *illus.* Castle House Publications, Tunbridge Wells, Kent, 1980. Price £6.

The title of this book is of course fatuous: the atmosphere is not endangered. Indeed, in an idle moment readers might like to imagine a means of accomplishing this proposition, and thereby come to a better appreciation of its improbability. As to the atmosphere being endangering, this is a prospect which arises mainly from it acting as a transporting medium for the manifold molecules emitted by the activities of the current human population; any reasonable cost–benefit analysis would still show the atmosphere to be undeserving of a ban by the various environmental protection agencies, however.

The vagaries of the process of title selection can be, one supposes, squarely blamed on the publishers, who also deserve a brickbat for publishing in 1980 the proceedings of a conference which took place over four years ago, a fact which can only be deduced indirectly from the book; however, the scientific editors must take responsibility for producing a text which is an uneven mixture of scientific and social commentaries.

The Preface was written by Margaret Mead; and while one hesitates to criticize this late social scientist of outstanding stature, a judgement which equates extreme caution among scientists to 'fiddling while Rome burns or dancing on the eve of the Battle of Waterloo' cannot be supported by experience in atmospheric science. This issue goes to the heart of the current environmental debate, particularly as far as the global aspects are concerned. The Preface as a whole calls for scientists to connect science effectively to political decision-making on a global scale, without however explicitly acknowledging the realities of a world of nation states. It is not obvious that global problems of the atmosphere cannot be solved within the present system; if they cannot, one is tempted to observe that they won't be.

*Part* 1*: Summary and recommendations.* This is yet another consideration of the now familiar catalogue of potentially large-scale pollution episodes: aircraft, nuclear weapons, fertilizers, chlorofluorocarbons, carbon dioxide, sulphur dioxide and radioactive gases ($^{85}Kr$ and $^{3}H$). At this stage, what matters most is not exactly what numbers are assigned to the effects of the various gases, but the way in which the inadequacies of the calculations are discussed. We are told that to ignore the possibilities of such changes is, in effect, a decision not to act. Such an assertion ignores the fact that one of the most uncertain things about these potential global pollution episodes is their time-scale, and that present models cannot predict the natural fluctuations of the quantities concerned; thus even if doubled $CO_2$ does increase surface temperatures in the models, and the effect does operate in the real atmosphere as calculated, there is no certainty that it will not be lost in the natural fluctuations. If long-range planning on a time-scale of decades is to be undertaken, then the concept of predicted effects being unequivocally above the level of natural variability should see more use than is apparent in this book.

In *Part* 2*: The atmosphere and its climate*, this difficulty is again returned to: one school of thought holds that calculations which predict 'great societal risk' should be acted upon, even if the calculations are incomplete, because there is no way of dismissing the possibility that the calculated effect will prevail. On the other hand, the position as stated by Smagorinsky 'If current physically comprehensive models are inadequate to answer some of our questions, then certainly we should be wary of basing broad national or international decisions on hand-waving arguments or back-of-the-envelope calculations' is characterized as extremely conservative. While your reviewer would replace 'hand-waving arguments or back-of-the-envelope calculations' by 'incomplete models'—and note that in his view there is no such thing as a 'current physically comprehensive model'—he sides with this second view.

*Part* 3*: Human costs and benefits of environmental change* again covers now familiar ground, with

human usage and supply of energy and food considered from varying points of view: scientific, economic and ecological. The analyses are brief, and usually argued by an individual participating in the conference; these authors are able to recommend the adoption of various strategies for future food and energy supply.

*Part* 4 summarizes the first day's discussion, and is a series of paragraphs describing the views of a succession of people identified mainly as 'a participant', 'one scientist', 'another scientist', 'a conferee', etc. The chapter conveys a good feeling of the quality and coherence of the discussion at a typical scientific conference.

*Part 5: Managing the atmospheric resource: Will mankind behave rationally?* is mainly about neither management nor behaviour, but is rather concerned largely with the way international law and organizations, such as the UN agencies, impinge upon national governments. To an atmospheric scientist, much of the argument seems hypothetical; the sprinkling of coal dust over the Arctic and Greenland ice caps, and large-scale weather modifications are one feels projects which have a long and hazardous road to travel prior to becoming actualities. The reader is also treated to the revelation that national governments react to international problems on the basis of maximizing benefit to themselves; this seems to be the main message, although it is obscured by the use of jargon like 'increasing and decreasing sum games', portentous statements of the obvious and startlingly confident expectations.

*Part 6: The atmosphere and society* is a position paper written before the conference by Kellogg, and defines the areas of interest for the participants: they are largely as listed in Part 1, with the addition of land-use changes, particle inputs and the addition of heat.

There are five appendices, dealing with (i) The carbon cycle and the palaeoclimatic record, (ii) The interaction of the atmosphere and biosphere, (iii) Some thoughts on control of aerospace, (iv) International structures for atmospheric problems, and (v) Some comments on technology and the atmosphere. Their fancifulness increases in the same order, and they form a suitably irritating end to an annoying book.

Throughout the book there are sections recording the arguments which took place at the conference, and although they are almost inevitably patchy, were nonetheless the most interesting passages, if only for seeing who said what about which topic.

This book has added yet another to the growing list of proceedings of international conferences on environmental matters which have been published in the last decade. It is a good deal worse than most of its predecessors, which in themselves were no great monuments to scientific insight or literary skill. The most effective course of action will be publication of the scientific work in journals, with national governments taking the best scientific advice available to them and acting as they see fit. Overblown jargon-laden statements about the need for international decision making, based on inadequately characterized atmospheric 'threats', are of no practical utility; this vapid volume abounds in them, and it cannot be recommended.

A. F. Tuck

*Chlorofluorocarbons in the environment: the aerosol controversy*, edited by T. M. Sugden and T. F. West. 235 mm × 155 mm, pp. 183, *illus*. Ellis Horwood Ltd, Chichester, Sussex, 1980. Price £17.50.

Having waxed unenthusiastic about the proceedings of a conference being published in book form in the previous review, it is a pleasure to be able to reverse attitude and recommend this volume. The crucial difference appears to be that selected, authoritative speakers were given a brief to produce a publishable paper at the meeting, and present it to a critical and informed audience. This advance

focusing effect, and the highly specific choice of subject, appears to have prevented the incoherent vagueness of the previous book. The conference took place in October 1978, and was set up by the Society of Chemical Industry.

*Chapter* 1, *Background and present position* by T. M. Sugden of Cambridge University, is a short survey of the background and position at the time of the conference. It is reasonable and balanced, laying some emphasis on the need for total risk analysis and the uncertainties in model results. It is slightly marred by the statement that the recovery time for stratospheric ozone from an all-out nuclear war would be about a century; this is not so, because the time-scale is the five years or so imposed by intra-stratospheric mixing rather than the decades required to cycle the entire atmospheric mass through the photochemically active regions of the stratosphere.

*Chapter* 2, *The chlorofluorocarbon/ozone issue: the industrial view*, is by G. Diprose of ICI Ltd, and gives an account of how the non-Eastern-bloc countries have organized a research program, through the then Manufacturing Chemists Association. The point is made that a program was organized in 1972, two years before the ozone depletion issue was raised by Rowland and Molina, to determine the ultimate fate of fluorocarbons in the environment. The long time-scale needed to build and amend the multiplant manufacturing process for these molecules, and their ideality for the uses to which they are put, are also pointed out. The research program is funded at \$1·4–2·0 million per year; the largest and most important work is that of the atmospheric lifetime experiment, where four or five stations have been set up on remote islands (distributed between both hemispheres) to measure as accurately as possible the trends in the atmospheric fluorocarbon mixing ratios, with the objective of thereby determining whether or not the actual lifetimes are in accord with those calculated by the models. A wide range of other activities is funded; one of these which has impinged on meteorologists is the conclusion drawn by statisticians experienced in the chemical industry, that total ozone measurements by the Dobson network are a better detector of long-term trends than many scientists associated with the instruments are willing to admit. This remains controversial. Finally, the expense and difficulty of finding suitable alternatives to fluorocarbons is presented.

*Chapter* 3, *Stratospheric chemistry* by B. A. Thrush of Cambridge University is a concise review of the chemical kinetics underlying the stratospheric ozone balance. He states a preference for the lower amounts of ClO measured in the upper stratosphere by Waters and by Anderson, rather than the inexplicably high profiles measured on two occasions by the latter. This view tends to be supported by Anderson's most recent data, but not by one set of measurements by Menzies in the upper stratosphere. As the author points out, a sufficient volume of data to establish a reasonable average is not available. After drawing attention to the cautionary tale of the predicted effects of supersonic transport aircraft, he further points out the inconsistency between theory and experiment in the matter of stratospheric concentrations of pernitric acid ($HO_2NO_2$) and nitrogen pentoxide ($N_2O_5$). After emphasizing the importance of uncertainty limits, the author expects these to be narrowed by continuing research, but with no dramatic changes in present understanding of the chemistry.

These papers are followed by a report of a discussion between named participants.

*Chapter* 4, *Halocarbons in the atmosphere* by J. E. Lovelock and P. G. Simmonds of Reading University is an account of the measurements made by the first of these authors, occasionally with collaborators, over the course of the 1970s. In a provocative chapter, issue is taken with those who criticized his first measurements of the interhemispheric ratio of $CFCl_3$ in 1971/72, and a convincing argument mounted that a true north–south ratio, at least over the Atlantic, needs a long time-series of measurements. From his position as inventor of the electron capture gas chromatograph, Lovelock points out the uncertainties in current measurements, which do not preclude the existence of significant tropospheric sinks for chlorofluorocarbons. He also points out the variability and relatively high abundance

of naturally occurring methyl chloride, and even proposes it as a possible atmospheric source of carbon tetrachloride, a molecule considered in other published work to be almost wholly of industrial origin. The matter is unresolved, but the points made are telling and require resolution.

*Chapter* 5, *Chlorofluorocarbons in the atmosphere: the meteorological problems* by R. J. Murgatroyd of the Meteorological Office is an examination of the relevant meteorological processes, and what is involved in their mathematical representation. Initially, it is stated qualitatively how the stratospheric composition, the radiation and motion fields are interactively coupled, an elementary point which, however, is still not represented in model calculations with sufficient thoroughness. The mean temperature and wind structure is described and interpreted, and followed by an account of the eddy motions of various sorts (sudden warmings, long waves, synoptic-scale features, etc.). The consequences of these motions for zonal mean modelling efforts are pointed out, and some results presented for the calculated transport of chlorofluorocarbons on a global scale. The conclusion is drawn that a better basis needs to be derived for one- and two-dimensional models, and that this will demand the preparation and analysis of adequate three-dimensional models.

*Chapter* 6, *Modelling stratospheric motions and their influence on ozone* by J. A. Pyle and J. T. Houghton of Oxford University, uses the two-dimensional zonal mean model developed in their department as a vehicle for discussion of the modelling of stratospheric ozone. Despite its ability to give reasonably realistic simulations, detailed considerations by the authors of the model reveals inadequacies in its representation of the large-scale eddy transfer coefficients by K theory. Significant latitudinal and seasonal effects are apparent in calculated ozone perturbations. The near balance between eddy transports of ozone and the mean meridional flux field they induce is shown, as is the dominance of the mean circulation in the hemispheric average of the vertical ozone flux. The concluding discussion on the status of extant models is balanced and useful.

An account of a discussion follows these three papers, and contains a debate involving *inter alios* Thrush, Pyle, Lovelock, Murgatroyd and Scorer.

*Chapter* 7, *Medical aspects: UV and skin cancer* by R. H. Mole of the Radiobiology Unit at Harwell, provides a description of the two most common but easily cured skin cancers, and of a third rarer but much more malignant tumour, melanoma, and their relationship to exposure in the UV-B radiation range, 280–320 nm wavelength. While many of the two commoner varieties can be ascribed to sunlight, the author points out that for melanoma the available data show latitude-independent temporal and spatial changes in frequency over the past quarter century which reflect altered social conventions of dress and skin exposure. The probable dependence of tumour induction upon the product of skin area exposed, UV flux and specific skin sensitivity means that latitude and environmental amounts of UV are inadequate indices for assessing UV effects. Finally it is pointed out that a small fractional increase in UV levels would result in a small fractional increase in skin cancer, whatever the dose response relationship, and that what matters is the absolute increase in numbers of cases.

*Chapter* 8, *The fluorocarbon/ozone issue: an industrial view* by R. L. McCarthy and F. A. Bower of du Pont and Co. is a trenchantly stated account from the United States standpoint. It states the main points clearly, emphasizing in particular the importance of the results sought by the atmospheric lifetime experiment and an investigation to determine the total chlorine mixing ratio in the stratosphere. Perhaps too much is expected from statistical modelling of time series of total ozone records from Dobson spectrophotometers; these data are claimed to provide an early warning system for CFM-induced reductions in ozone with a higher sensitivity than is admitted by those who actually make the observations. Finally it is concluded that FC–22 ($CHClF_2$) is the only alternative compound in sight for FC–11 and 12 ($CFCl_3$ and $CF_2Cl_2$), but that even this molecule has substantial reservations attached. The authors were unable to resist making the observation that 'In the United States, as you are well

aware, the regulatory decision has been made with regard to aerosols in the absence of compelling science'.

*Chapter* 9, *Fluorocarbons in the European polyurethane foam industry by* B. M. Grieveson of Shell Research, Amsterdam, is a listing of the usage of fluorocarbons in blowing foams, and is very brief, as befits what in Europe is a relatively low fraction of the total production; nevertheless, no alternative is known, and it is pointed out that the cessation of polyurethane foam manufacture would substantially increase costs in the furniture industry.

*Chapter* 10, *A Continental European industrial viewpoint* by G. von Schweinichen of Montedison/Milan, is a bluntly stated case for following the European Council of Ministers line: namely, wait for better evidence and understanding but in the meantime permit no increase in production. The evidence is examined and found inadequate as a base for legislation. The US Environmental Protection Agency's concept of essentiality is criticized, and an alternative offered; a rigorous definition is difficult, but the author clearly prefers a stronger role for the market in determining what is essential. It is pointed out that the banning of fluorocarbons would have substantial effects on the supply and demand of several chemicals which are involved as feedstocks and by-products, and would have an economic impact three times as large as the direct losses.

A fourth discussion follows the above papers, succeeded finally by *Chapter* 11, *Aerosols* by R. A. Gunn-Smith of Metal Box and D. J. Smith of British Aerosol Manufacturers' Association. This is a description, partly historical, of the development of chlorofluoromethane aerosol sprays as 'bug bombs' in the Pacific campaign of the Second World War and their advantages in the post-war market place, as attested by rapid growth to a production of $6 \times 10^9$ fillings in 1974. Since then production of aerosols has levelled off and declined; alternatives such as hydrocarbons, cheaper but inflammable, are being introduced as bans have been or are to be introduced in the US, Holland, Sweden and Norway.

The book provides a British/European view; it gains from having industry's viewpoint presented, and despite having eleven independent bricks and little mortar does give a fairly coherent picture. What is noticeably missing is an enthusiastic proponent of an EPA-style ban; is it, one wonders, because individuals of sufficient stature holding these views do not exist in the United Kingdom?

A. F. Tuck

## Honours

The following honours were announced in the Queen's Birthday Honours List 1980:

I.S.O.

Mr C. L. Hawson, who at the time of his retirement was a Principal Scientific Officer in the Special Investigations Branch, Meteorological Office, Bracknell.

M.B.E.

Mr S. R. Smith, Telecommunications Technical Officer I, Meteorological Office Radar Research Laboratory, Malvern.

I.S.M.

Mr W. G. Estcourt, Radio Operator, Telecommunications Branch, Meteorological Office, Bracknell.

## Obituary

We regret to record the death on 16 March 1980 of Mr T. Kelly, Senior Scientific Officer, who was stationed at the Main Meteorological Office, Gloucester. Tom Kelly joined the Office as an Assistant Experimental Officer in November 1950 and served at a variety of stations at home and overseas, including tours at Fayid, Negombo (Ceylon), Muharraq and Rheindahlen; he also worked for several years at the London Forecast Office. He was promoted to Experimental Officer in 1954 and to Senior Experimental Officer in 1965. He and his wife Sue, who predeceased him in 1977, will long be remembered for their kindness and hospitality by the many Office staff and their wives who served with them in Germany, the Middle East and the Far East.

We regret to record the death on 20 March 1980 of Mr T. S. Douglas, Higher Scientific Officer, who was stationed at Prestwick. He joined the Office as an Assistant in August 1941, and served at a number of outstations (including London Airport), and on weather ships. In 1955 he went to Stornoway on promotion to Senior Scientific Assistant. In 1959 he was posted to Prestwick where, with the exception of an overseas tour to Bahrain, he remained for the rest of his life, being promoted to Higher Scientific Officer in 1978. His shrewd and well-informed advice to the forecasting staff at stations controlled by Prestwick was always helpful and will be sorely missed.

THE METEOROLOGICAL MAGAZINE

No. 1298 September 1980 Vol. 109

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NOTICES

It is requested that all books for review and communications for the Editor be addressed to the Director-General, Meteorological Office, London Road, Bracknell, Berkshire RG12 2SZ, and marked 'For Meteorological Magazine'.

The responsibility for facts and opinions expressed in the signed articles and letters published in this magazine rests with their respective authors.

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Issues in Microfiche starting with Volume 58 may be obtained from Johnson Associates Inc., P.O. Box 1017, Greenwich, Conn. 06830, U.S.A.



Printed in England by Heffers Printers Ltd, Cambridge
and published by
HER MAJESTY'S STATIONERY OFFICE

**£1.60 monthly**
Dd. 698260 K15 9/80

**Annual subscription £21.18 including postage**
ISBN 0 11 722065 5
ISSN 0026–1149